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TRAVELING CHARGE COMPUTATIONS - EXPERIMENTAL COMPARISONS AND SENSITIVITY STUDIES

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Theoretical performance studies were conducted for a 14 mm gun operated in the conventional and traveling charge (TC) modes using the XKTC interior ballistic code. Conventional charge calculations, done by way of model validation, agreed closely with experimental firings. Traveling charge calculations were done to predict the effects of varying parameters such as TC ignition time and burning behavior on charge performance. For a propelling charge composed of a conventional booster propellant and a TC element, delaying TC ignition past maximum pressure from the booster predicts the greatest improvement in TC performance. TC performance appeared to be less sensitive to the details of burning rate pressure dependence than to overall TC element burn time. Uncontrolled burning characterized by very short burn times leads to excessive gun pressures.

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I. INTRODUCTION

The traveling charge concept or "impulse gun" originally proposed by Langweiler[1] is considered by ballisticians to offer the prospect of obtaining muzzle velocities on the order of 2 to 3 km/s without the large(~4)[2] charge to mass ratio and high breech pressures(700-1000 MPa)[3] required of conventional gun systems. The advantages of such velocities have been discussed by various authors[1-3] and can be summarized as improved delivery range, increased target penetration due to higher kinetic energy of the projectile, and enhanced hit probability resulting from the decreased time-of-flight.

It is not within the scope of this report to present a theoretical analysis of the traveling charge concept or review previous experimental results. The interested reader is referred to the works of Langweiler,[1] Lee and Laidler,[4] Vinti,[5] Gough,[6-7] Baer,[8] May et al.,[3] and Briand et al.[2] for a discussion of the theoretical analysis and development of computer models for the traveling charge concept. Findings of previous experimental efforts can be found in reports by O'Donnell et al.,[9] Baer,[10] Barbarek and Jeslis,[11] Baldini and Audette,[12] and May et al.[3] An idealized description of the traveling charge effect has been presented in an earlier work by Smith[13] and is shown in Figure 1. The ignition process is in two stages. A conventional "booster" charge is used to rapidly pressurize the chamber and accelerate both the projectile and a propellant charge(traveling charge) attached to the base of the projectile. At some point past the peak pressure due to the "booster" charge, the traveling charge is ignited. It burns in such a manner as to generate and eject combustion products at sufficient velocity to maintain constant thrust/pressure on the projectile base and to increase projectile velocity. At very high velocities, the traveling charge is expected to be more efficient than conventional propelling charges. An example of this is included in Table A-2.

TRAVELING CHARGE GUN

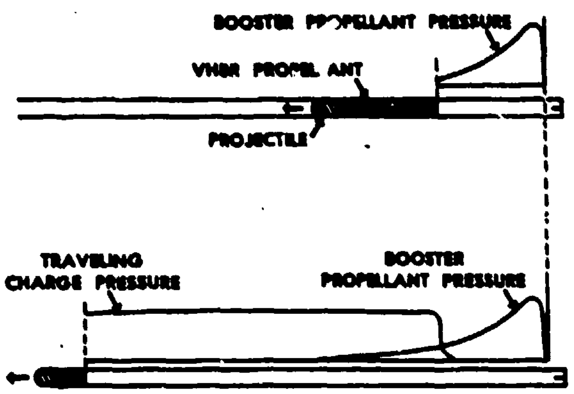


Figure 1. Idealized Traveling Charge Gun[13]

In summary, the traveling charge effect is characterized by:

a) The attachment to the projectile of a very high burning rate(VHBR) propellant which travels with the projectile down the tube.

b) Deviation from the "normal" pressure gradient which would be obtained if all the propellant, "booster" and traveling charge, were placed in the chamber. The deviation should show lower chamber pressures and increased downbore pressures.

c) An increase in muzzle velocity over the corresponding conventional firing.

At the present time, we are undertaking an experimental effort to demonstrate the traveling charge effect as a practical and useful gun propulsion system. An important component of this effort is the use of a sophisticated computer code, XNOVAKTC (XKTC), which can model both traveling charge and conventional gun firings. As stated by May et al.,[3] a flexible computer model

> "is necessary as a learning tool to help explore the consequences of the physics that has been incorporated, and to guide the experimental program."

The purpose of this report is to summarize the results of the initial modeling computations which were part of the above effort. These computations include investigations in the following areas:

Applicability of the XKTC computer code to a small caliber (14-mm) Mann Barrel, a regime in which the code had not previously been exercised. In this setting the predictive nature of XKTC for both conventional and traveling charge firings is examined relative to experimental results.

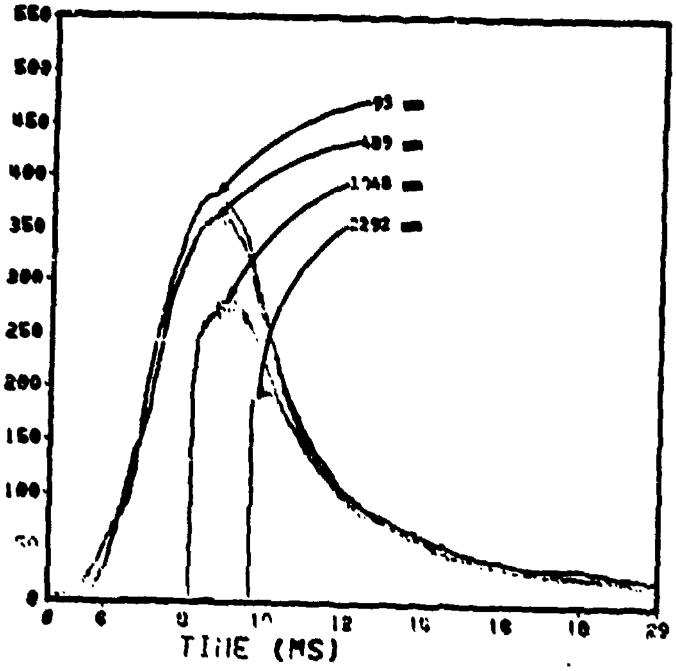
Sensitivity of the traveling charge effect to the ignition time of the traveling charge propellant. This parametric study incorporated two distinct burning rate laws for the traveling charge due to the uncertainty of the burning behavior of the VHBR propellant.

Sensitivity of the traveling charge effect to the burning rate of the traveling charge propellant.

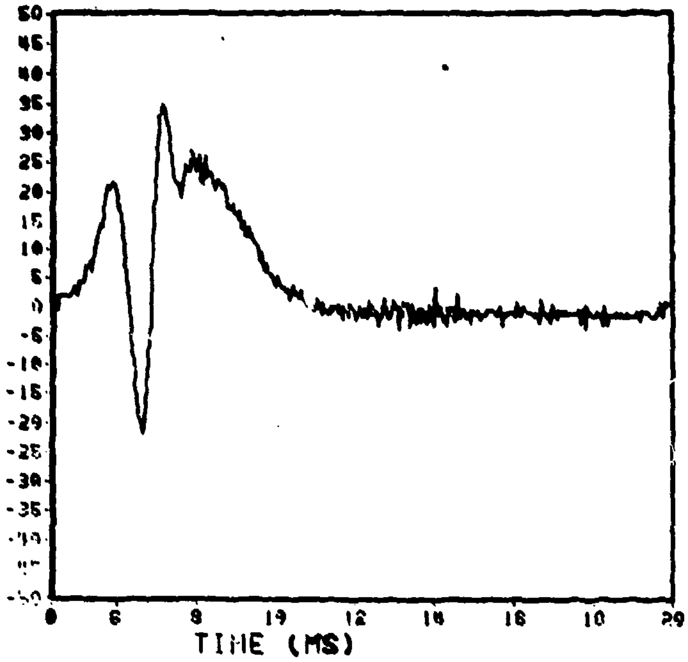
II. XKTC COMPUTER CODE

The computer code selected to model the interior ballistic event was the XNOVAKTC (XKTC) code developed by Paul Gough Associates. This code is a combination of a newer version of the NOVA[14] code together with the BRLTC[6]

code. Selection of XKTC was based upon several factors. First, the code has the capability to model conventional, traveling charge, and a combination of "booster" and traveling charge gun firings. Second, the code includes kinetic options which allow flexibility in investigating the traveling charge effect. The details of the kinetic options pertaining to the traveling charge were presented by P. Gough in a separate paper.[15] The final factor in selecting XKTC was its demonstrated accuracy in predicting gun performance, in terms of pressure profiles, pressure oscillations, and velocity, at least for large caliber conventional gun firings. This accuracy is illustrated for a 120-mm tank gun in a paper by Robbins et al.[16] Figure 2 shows the measured pressures at various positions along the gun tube and pressure difference measured between the ends of the chamber for a 120-mm caseless round. Figure 3 presents the pressures and pressure difference calculated by XKTC for the caseless round. A comparison of the pressure and pressure difference curves for the measured and calculated results shows excellent agreement. The difference in breech pressures is approximately 4 MPa while at the muzzle the difference is about 7 MPa. Also, the curves for the pressure differences, which measure the pressure oscillations in the chamber, have the same general characteristics.

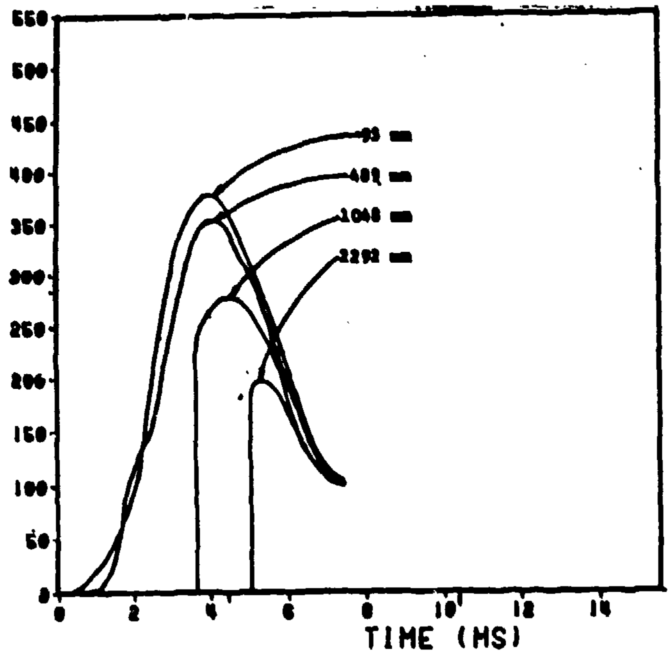


Pressures (MPa)

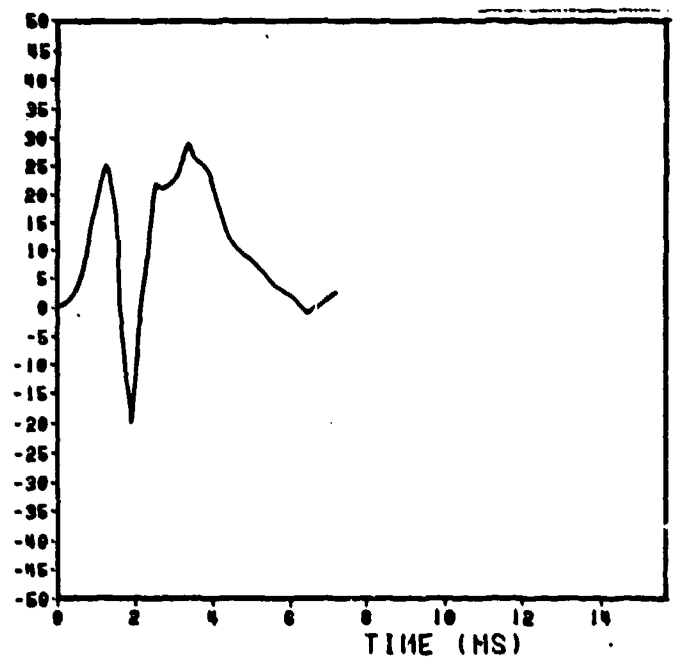


Pressure Difference (MPa)

Figure 2. Experimental Pressure and Pressure Difference Curves for a Caseless Round Fired in a Conventional 120-mm Gun



Pressures (MPa)



Pressure Difference (MPa)

Figure 3. Pressures and Pressure Difference Curves ar Calculated by XKTC for a Caseless Round Fired in a Conventional 120-mm Gun

Although XKTC showed excellent agreement for large caliber gun systems, its predictive ability for small caliber systems was unknown. Therefore, code validation was extended to small caliber applications and used as a tool to evaluate ballistic improvements due to the traveling charge effect.

II. EXPERIMENTAL FIXTURE AND GUN FIRINGS

A schematic of the test gun fixture together with the location of pressure gages is shown in Figure 4. The fixture has a chamber volume of 100 cm^3, a bore diameter of 14-mm, a tube length of 2900-mm and an expansion ratio of 5.3. A schematic of the traveling charge projectile to scale is presented in Figure 5.

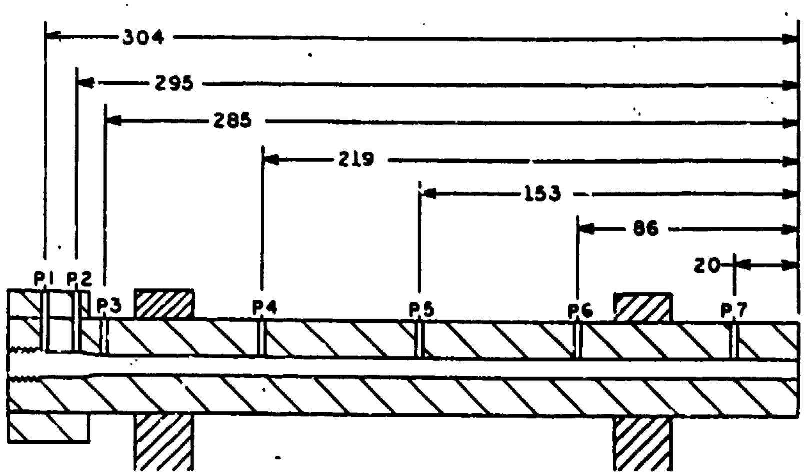


Figure 4. Schematic of the Experimental Gun Fixture (dimensions in cm)

Figure 5. Traveling Charge Projectile

At the time of this report 12 firings with 6 different configurations of "booster" and traveling charge propellant have been performed. Details on these firings can be found in a separate paper.[17] For this study, two of these firings were selected for detailed analysis. The configurations for these firings are shown in Table 1.

TABLE 1. Configuration of Firings Used in Study

Round #	Booster (g)	T.C. (g)	Projectile (g)
6	34	--	24.59
12	34	8.53	22.0

For round 6, the cavity of the traveling charge projectile was filled with a nylon insert. The "booster" charge for both rounds was a non-deterred ball propellant manufactured by the Olin Corporation. The traveling charge propellant used in round 12 was a combination of RDX and a boron hydride salt with a KRATON binder pressed to 100% theoretical maximum density. Results are tabulated in Table 2. Pressures are given in MPa and velocity in m/s.

TABLE 2. Experimental Results Of Rounds 6 and 12

Rd #	Gage 1 Pmax MPa	Gage 2 Pmax MPa	Gage 3 Pmax MPa	Gage 5 Pmax MPa	Gage 7 Pmax KPa	Velocity m/s
6	339	325	281	71	29	1567
12	555	458	590	98	44	1770

Pressure vs. time curves for the two rounds at the indicated gages are given in Figures 6 and 7.

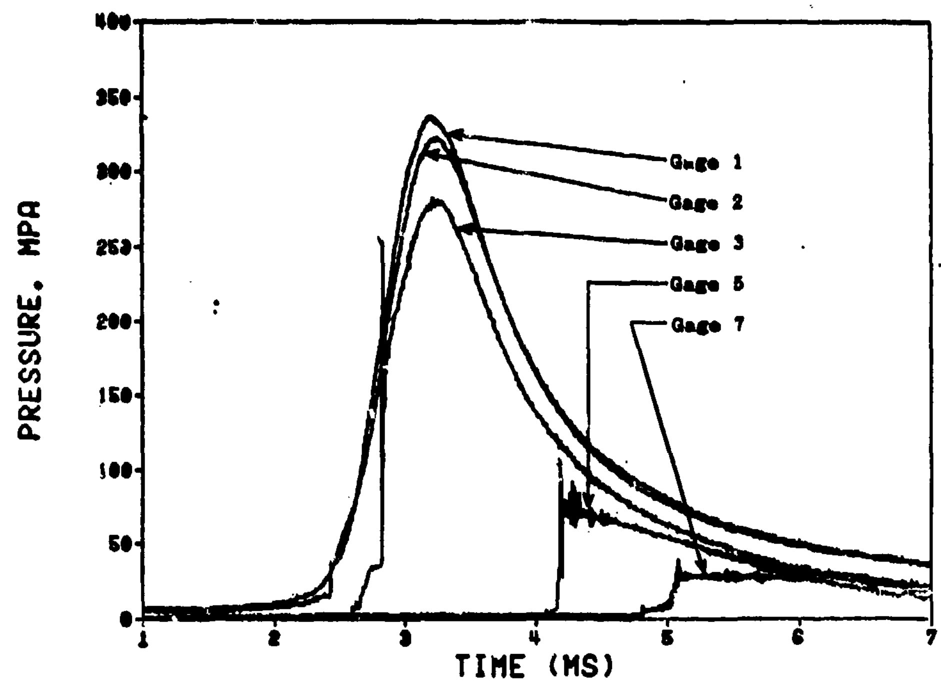


Figure 6. <u>Experimental Pressure Versus Time for Round 6 Conventional Firing</u>

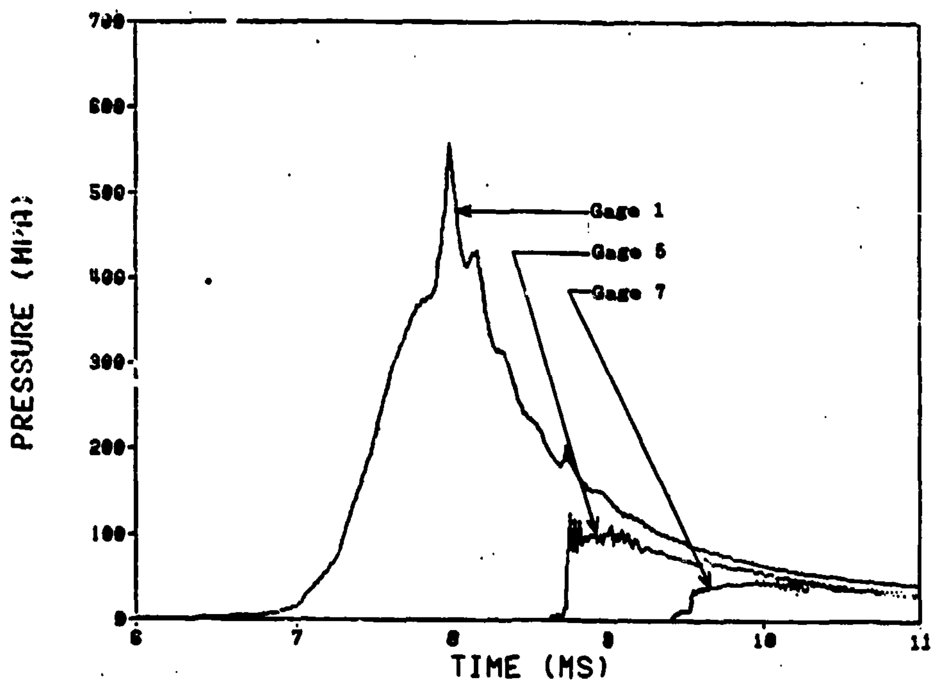


Figure 7. <u>Experimental Pressure Versus Time for Round 12 Traveling Charge Firing</u>

IV. COMPARISONS BETWEEN XKTC AND EXPERIMENTAL MEASUREMENTS

Although the XKTC code has never been fully exercised for small caliber guns, because of its agreement with experimental results from large caliber firings, it was expected that the code would also be in good agreement with small caliber firings.[18] Thus, the only parameters adjusted in the code in attempting to match experimental results were bore resistance and shot start pressure.

Thermochemical information for the "booster" propellant was obtained through the use of the BLAKE[19] code. Burning rates for the "booster" were obtained from closed bomb firings and subsequent data reduction using CBRED2.[20] For the purposes of simplification, the thermochemical properties of the traveling charge propellant were assumed to be identical to those of the "booster". However, the burning rate for the traveling charge was adjusted to produce burning times similar to those obtained in the closed bomb diagnostic work.[17]

Discussion of Round 6: To simulate round 6, the XKTC code was run in a conventional gun firing mode. Table 3 shows the final computed results after a series of parametric runs involving varying the shot start pressure and bore resistance profile. The final values selected were a shot start of 6 MPa and a bore resistance of 19 MPa from 51 cm of travel to muzzle exit. Although the bore resistance profile is unusual in that the resistance increases after a certain amount of travel it was felt that this situation was not physically impossible. This belief was based upon the design of the projectile which had a very thin walled sleeve. It was felt that the pressure exerted on the sleeve was sufficient to distend the sleeve resulting in the higher resistance used in the computer model. Also presented in the table is a comparison with experimental results.

Computed pressure vs. time profiles from XKTC for round 6 are presented in Figure 8. A comparison with the experimental pressure profiles, Figure 6, shows the excellent agreement for breech pressures as indicated in Table 2. Differences in the downbore pressures are also clearly evident. Fortunately, the timing of the events (uncovering of gage locations, etc.) are in close agreement, which agrees with the close match on the velocities.

TABLE 3. Comparison of Predicted XKTC Results and Experimental Results for Round 6 -- Conventional Firing

Gage 1 Pmax MPa	Gage 2 Pmax MPa	Gage 3 Pmax MPa	Gage 5 Pmax MPa	Gage 7 Pmax MPa	Velocity Interferometer m/s
XKTC Round 6:					
341	338	275	65	28	1571
Experimental Round 6:					
339	325	281	71	29	1567
Difference:					
2	13	-6	-6	-1	4
Percent Difference:					
.6%	4%	-2%	-8.5%	-3%	.25%

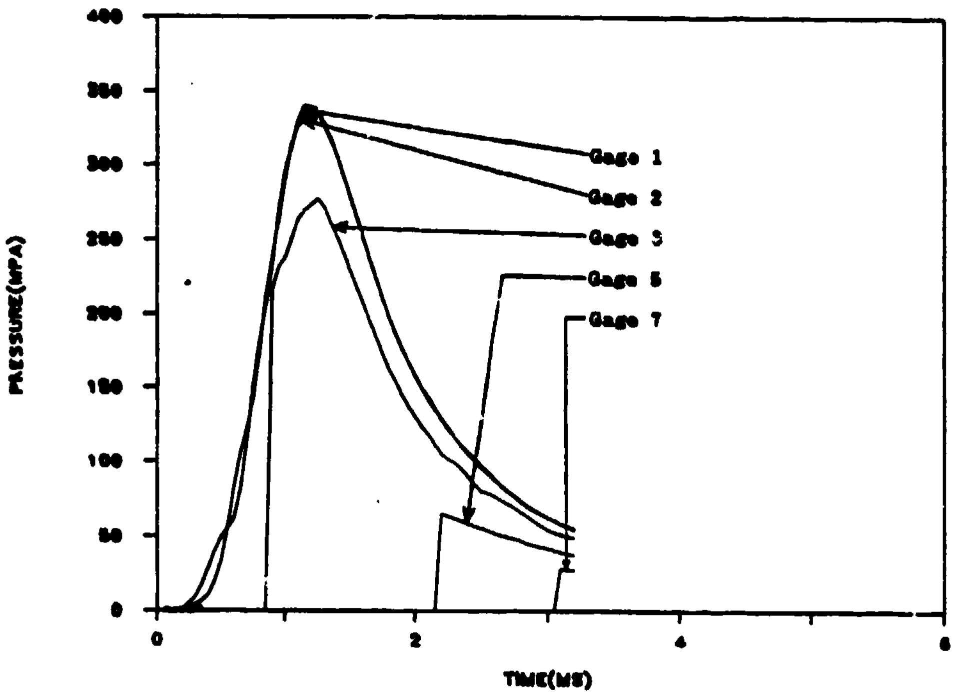


Figure 8. Computed Pressure Vs. Time Profiles From XKTC for Round 6 Conventional Firing

For both the 120-mm conventional caseless firing presented earlier and this small caliber (14-mm) conventional firing, XKTC appears to accurately predict breech pressure, timing, and velocity. On the other hand, a difference between measured and computed downbore pressures is present in both comparisons. Whether these differences are due to incorrect resistance profiles or other causes needs to be investigated in more depth.

Discussion of Round 12: The traveling charge option of the XKTC code was used to simulate round 12. Given the success in matching experimental results for round 6, all input variables, except those pertaining to the traveling charge and "booster" charge weight, were kept the same. A burning rate law ($r=bP^n$, where b=0.065 and n=1.05) was used to describe the traveling charge burning. Further, the ignition of the the traveling charge was delayed 1.15 ms after the ignition of the "booster" charge. The time delay for the traveling charge was estimated from the pressure vs. time curves from the experimental results. Table 4 summarizes the computed results and comparisons with the experimental data.

TABLE 4. Comparison of Predicted XKTC Results and Experimental Results for Round 12 -- Traveling Charge Firing

Gage 1 Pmax MPa	Gage 2 Pmax MPa	Gage 3 Pmax MPa	Gage 5 Pmax MPa	Gage 7 Pmax MPa	Velocity Breakscreen m/s
XKTC Round 12:					
554	472	620	89	39	1782
Experimental Round 12:					
555	458	590	98	44	1770
Difference:					
-1	14	30	-9	-5	12
Percent Difference:					
-.2%	3%	5%	-9%	-11%	.7%

The pressure vs. time curves, for round 12, computed by XKTC are shown in Figure 9. As in the two previous comparisons, XKTC results are in close agreement with experimental results for breech pressure, timing, and velocity.

But once again, substantial differences are observed in the downbore pressures especially for gage 5. Fortunately, the pressure vs. time curves computed by XKTC exhibit the same behavior as the experimental pressure vs. time curves for gages not located at the breech. An example of this close agreement is shown for gage 3, (tube origin) in Figures 10 and 11.

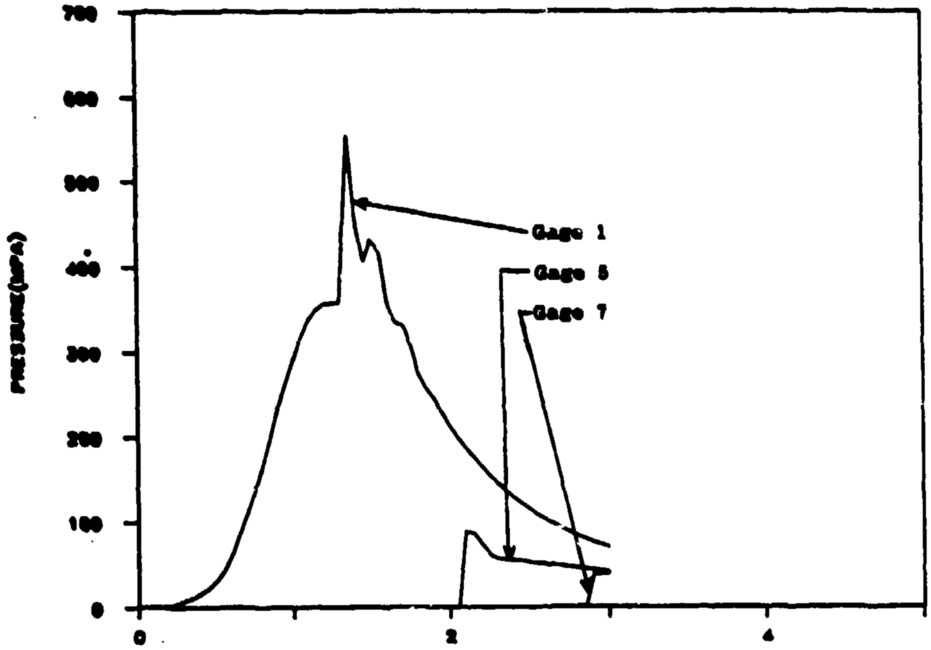


Figure 9. Computed Pressure Vs. Time Profiles From XKTC For Round 12 -- Traveling Charge Firing

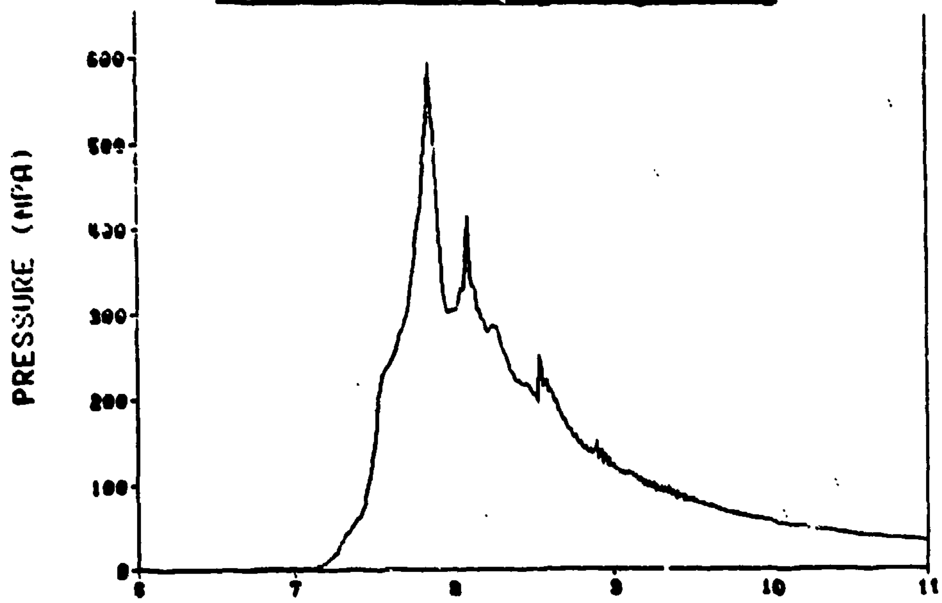


Figure 10. Experimental Pressure Vs. Time Curve, Round 12 Gage 3 (Tube Origin) -- Traveling Charge Firing

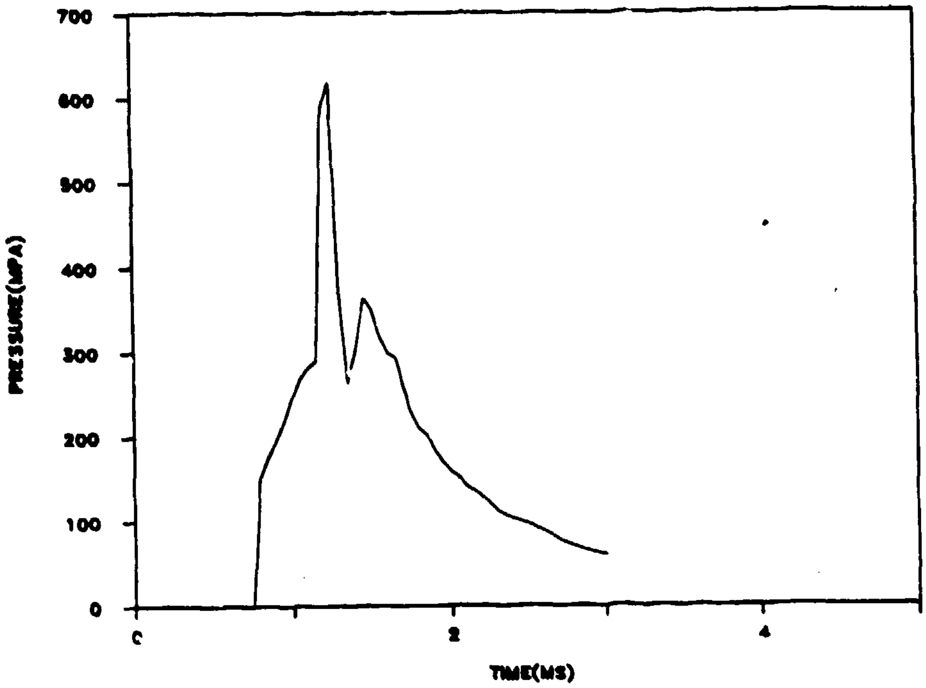


Figure 11. Computed XKTC Pressure Vs. Time Curve Round 12 Gage 3 (Tube Origin) - Traveling Charge Firing

V. IGNITION TIME STUDY

In concept, it is possible to place the entire charge at the projectile base without using any propellant in the chamber. However, from previous computations[8] it appears that there is little gain in efficiency in using a traveling charge for the early portion of the ballistic cycle. On a more practical side, the early portion of the ballistic travel can be greatly affected by combustion variability and at this time there is some uncertainty concerning the predictability of the burn rate of the VHBR formulations. Additionally, the pressure drop at the projectile base is relatively small when the projectile velocity is low. Hence, for these reasons it was decided to use a conventional "booster" propellant for the initial travel and have the traveling charge ignite after the projectile has moved down tube. An important question to address is: "Where is the most advantageous position in the ballistic cycle to ignite the traveling charge?"

The purpose of investigating the ignition time of the traveling charge was to determine its effect on muzzle velocity and maximum pressure within the gun.

For the study, a traveling charge configuration similar to that of round 12 was used; that is, 34 grams of "booster" propellant with 8 grams of traveling charge. Due to the uncertainty of the actual burning behavior of VHBR propellants, two different burning rate laws were utilized. First, was the pressure dependent law used in simulating round 12, $r = 0.065P^{1.05}$. The second was a constant burning rate of 71 meters/second, a rate which would ensure the burn out of the traveling charge prior to muzzle exit. In

addition, no bore resistance was incorporated into the model. It should also be noted that no attempt was made to optimize the system with respect to performance due to the "booster" charge.

As a point of comparison, an all "booster" case with 42 grams of propellant was selected. Results of this all "booster" case showed a maximum gun pressure of 496 MPa and a muzzle velocity of 1897 m/s.

The ignition time of the traveling charge with respect to the "booster" ignition time was made a parameter in the calculations. The actual times used in the study were based upon the assumption that the traveling charge would ignite no later than the time necessary to obtain 25% of travel. From the all "booster" case the time to 25% of travel was 1.75 ms and the time of maximum pressure was 1.15 ms. Figure 12 summarizes the times selected for the study.

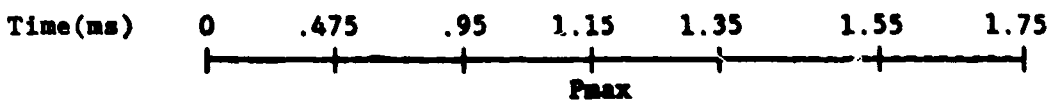


Figure 12. <u>Ignition Times Chosen for the Traveling Charge in the Ignition Time Study</u>

The effect of changing the ignition time of the traveling charge was evaluated in the following manner. Pressure vs. time curves for the all "booster" run were compared with those from the traveling charge cases for the different traveling charge propellant ignition times. Differences in maximum pressure and corresponding percent differences, with respect to the all "booster" case, were determined. Similar comparisons were performed for differences in velocity. An example of this computation is shown in Figure 13 for the 42 gram all "booster" comparison case versus a traveling charge simulation with an ignitions delay of 1.75 ms. The difference between maximum pressures is 147 MPa, which represents a percent decrease of 30% with respect to the comparison case. These percent changes in maximum pressure and velocity, as a function of traveling charge ignition time, are presented graphically in Figures 14 and 15.

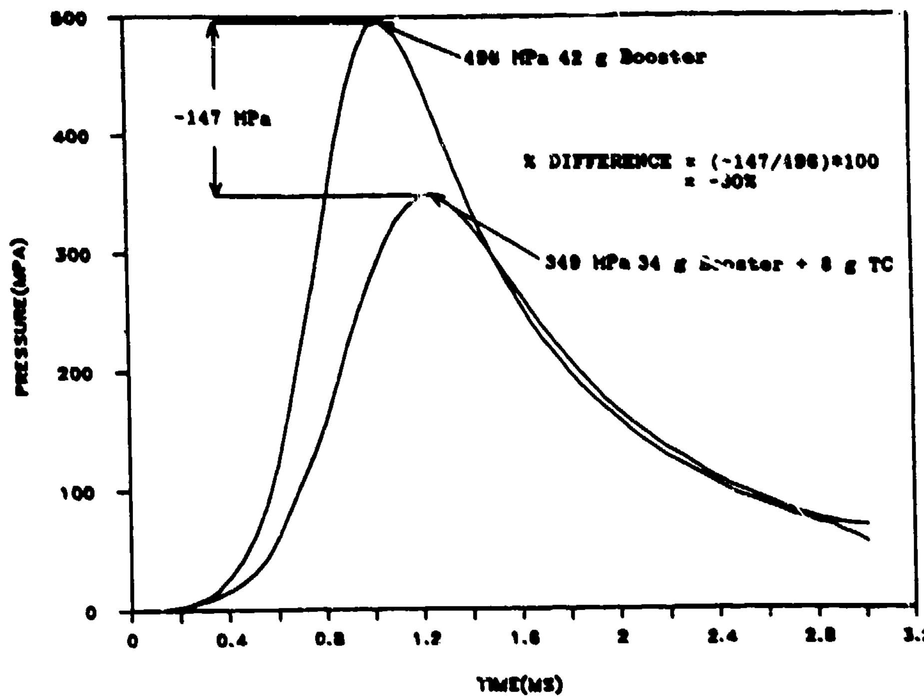


Figure 13. Computation of Percent Difference in Maximum Pressure Between 42 g All "Booster" Comparison Case and a Traveling Charge Firing Used in the Ignition Time Study

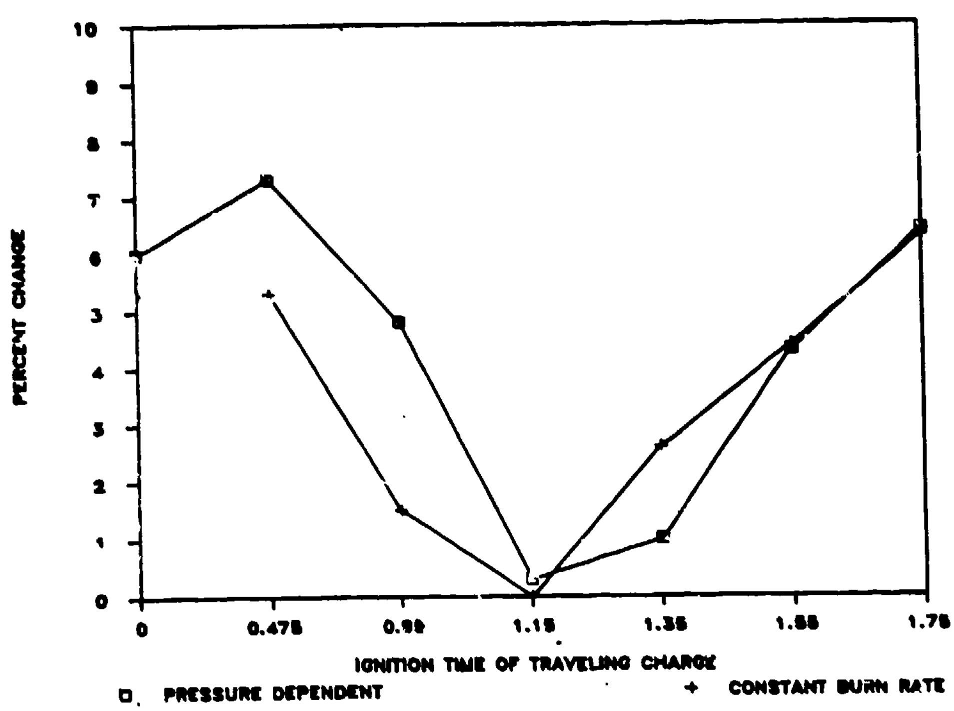


Figure 14. Percent Change in Muzzle Velocity Vs. Traveling Charge Ignition Time

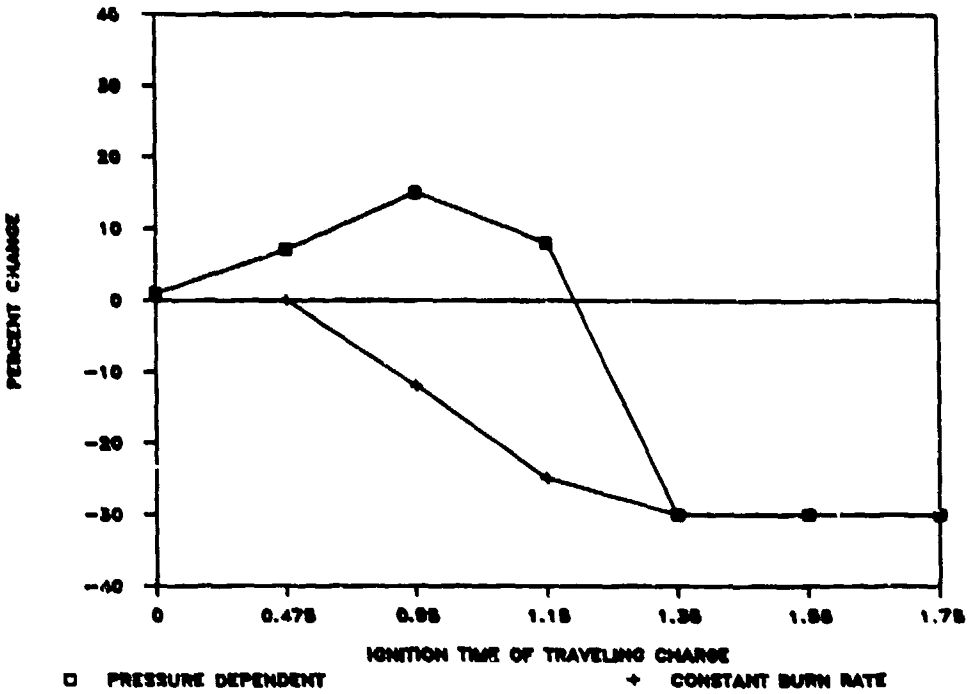


Figure 15. Percent Change in Maximum Pressure Vs. Traveling Charge Ignition Time

As can be seen from Figure 14, XKTC predicts a velocity increase for a configuration of 34 grams of "booster" and 8 grams of traveling charge propellant over the all "booster" case regardless of the ignition time of the traveling charge propellant. The only exception was the simulation using a constant burn rate law with ignition at 1.15 ms which resulted in the same velocity. It appears that the critical factor for the increased velocities is the deviation of the ignition time from 1.15 ms, which is the time of Pmax for the all "booster" case. For the pressure dependent burn rate law the maximum percent increase in velocity of 7.3% occurred at an ignition time of 0.475 ms, a deviation of 0.675 ms from 1.15 ms. Using the constant burn rate law, the maximum percent increase, 6.3%, in velocity occurred for an ignition time of 1.75 ms, a deviation of 0.6 ms from 1.15 ms. This same percent increase, 6.3%, was also computed for the pressure dependent burn rate law with ignition at 1.75 ms. Of interest is the lower percent increase in velocity recorded for an ignition time of 0 ms than for an ignition time of 0.475 ms with the pressure dependent burn rate law. The cause of this drop needs to be investigated in greater detail.

Although velocity increases are predicted by XKTC for ignition times both before and after 1.15 ms, the same thing is not true for improvements in the pressure profile as far as maximum gun pressure is concerned. As shown in Figure 15, a time of ignition before or at 1.15 ms shows an <u>increase</u> in predicted maximum pressure for the pressure dependent burn rate law. Using a constant burn rate law no increase in pressure is obtained for the same

ignition times. However, both burn rate laws exhibit a 30% maximum pressure <u>decrease</u> if the ignition time is 1.35 ms or later. In all instances, the maximum pressure is observed at the breech.

Thus, for the ignition times selected and the specific gun/propulsion case used in this study, XKTC predicts that the maximum improvement to the traveling charge effect will occur for an ignition time of 1.75 ms for the traveling charge propellant. It is important to emphasize that this conclusion is applicable only to this specific case. Any change in the gun/propulsion configuration, such as changing the ratio of "booster" to traveling charge propellant, may lead to a different predictions.

Two additional observations noted while analyzing the results of the ignition time study are worth mentioning. First is the apparent insensitivity of the results to the burn rate law used to describe the burning of the traveling charge propellant. This facet needs to be investigated in greater depth, especially since combustion diagnostics on the VHBR propellants have indicated that their burning behavior may not be pressure dependent in the normal sense.[17] The second observation concerned downbore pressures. In APPENDIX A, Tables A-1 and A-2 show the maximum pressure predicted by XKTC for the various gages, ignition times, and burn rate laws used in the study. It was observed that for gage 7, located 20-cm before muzzle exit, the pressures for the traveling charge cases were lower than the all "booster" case with one exception. Additionally, the maximum pressure observed at gage 7 in all cases corresponds to the base pressure on the projectile. However, muzzle velocities, which are reflective of base pressure, are higher for the traveling charge cases. An answer to this apparent contradiction may lie in the effect that the burn out of the traveling charge has on the base pressure. In Figure 16, XKTC computed base pressure versus travel profiles are plotted for the all "booster" case and two traveling charge cases. The rapid drop in the base pressure curves for both traveling charge cases occurs at the point in the travel where the traveling charge burned out. This rapid drop in both cases resulted in the base pressure being <u>lower</u> than the base pressure for the all "booster" case. Thus, it appears that the burn out of the traveling charge may have a substantial effect on base pressure. If this effect is present in actual gun firings, then tailoring the burn out of the traveling charge may be as critical to final performance as the ignition time of the traveling charge.

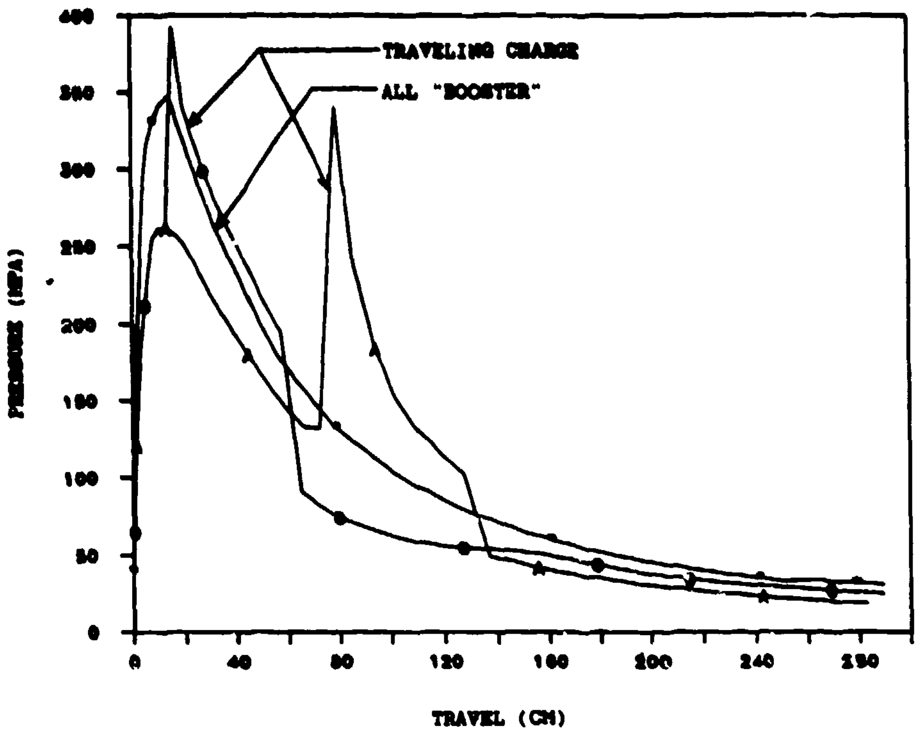


Figure 16. Base Pressure Vs. Projectile Travel for: * All "Booster"; o Traveling Charge Ignited at 1.15 ms; Δ Traveling Charge Ignited at 1.75 ms.

VI. BURNING RATE STUDY

In the ignition time study two different burn rate laws were utilized to describe the burning behavior of the traveling charge propellant, a) r = 71 m/s, a constant burn rate and b) $r = 0.065P^{1.05}$, a pressure dependent exponential law. Comparison of results showed some differences, especially in pressure behavior, between predictions involving the two laws. Thus, it became of interest to examine in greater detail the influence of the burning behavior of the traveling charge on predicted ballistic results. For this study the focus was on the effect of using different burning rates.

Specifically, the purpose of this study was to investigate the effect that different burning rates of the traveling charge have on ballistic performance. Again the parameters of major interest are velocity and maximum gun pressure.

As in the ignition time study, a traveling charge configuration of 34 grams of "booster" and 8 grams of traveling charge was selected. Based upon the result of the ignition time study, the ignition time of the traveling charge was chosen to be 1.75 ms. A bP^n burn rate law, with b=.065 and n=1.05, was used in the the study; and the variation in the burn rates was obtained by varying the value of the coefficient by +/-30, +/-20,+/-15, +/-10, and +/-

5 percent.

Figures 17 and 18 present the effects of variations in burning rate, as predicted by XKTC, on the maximum pressure recorded in the gun and muzzle velocity in terms of percent changes.

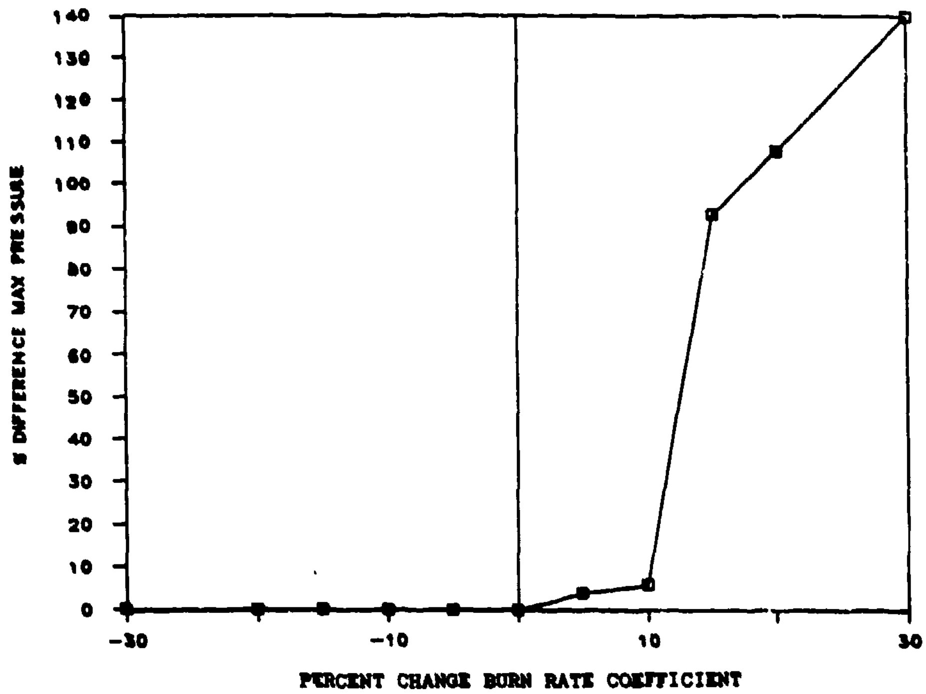


Figure 17. <u>Effect of Varying the Burning Rate of the Traveling Charge on Maximum Gun Pressure</u>

The most striking feature of Figure 17 is the very large change in maximum gun pressure, up to 140%, which is predicted by XKTC for increases in the burning rate of the traveling charge beyond a 10% increase. If this result is valid for actual gun firings, then controlling the burning rate of the VHBR propellant may be of critical importance for improved ballistic behavior. In fact, it may be that there is a narrow range for the burning rate of the VHBR for which the traveling charge effect can be effective. Too low a burning rate producing no appreciable gain and too high a rate resulting in unacceptable pressures. It is worth noting that the elevated pressures for the increased burning rates in Figure 17 occurred at the projectile/traveling charge base not the breech.

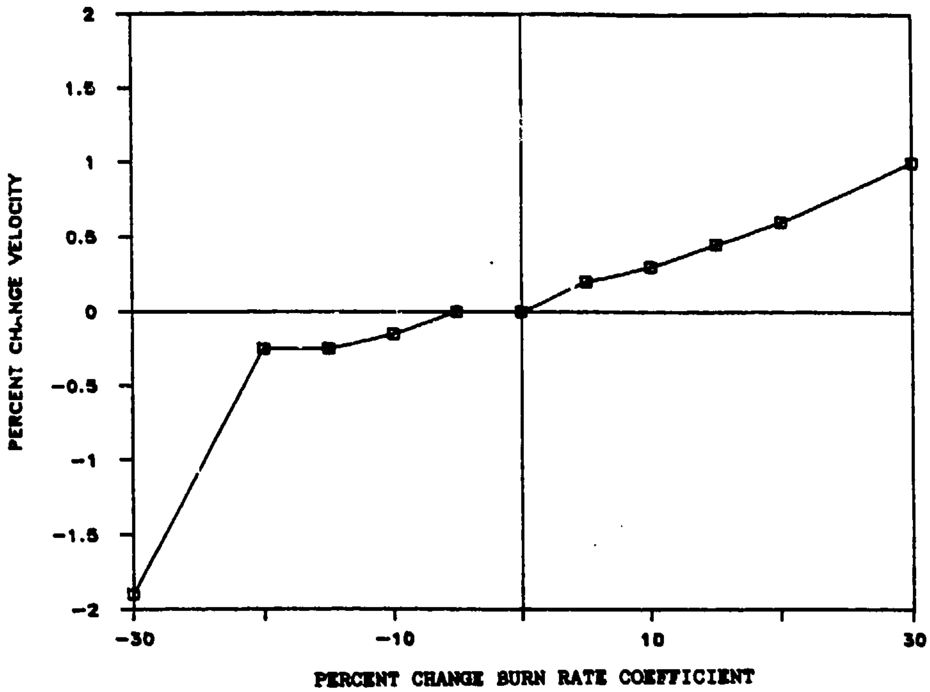


Figure 18. Effect of Varying the Burning Rate of the Traveling Charge on Muzzle Velocity

Although increased maximum gun pressures are predicted by XKTC for increased burning rates of the traveling charge, this is not translated into appreciable increases in velocity as seen in Figure 18. For changes in the burning rate up to +/- 20% the velocity changes by less than +/- 0.5%. However, the large drop from -0.25% to -1.9% in going from 20% to 30% decrease in burning rate may indicate that there will be a significant decrease in performance if the burning rate of the traveling charge is too low.

As with the ignition time study, the conclusions reached are based on predicted results for a specific gun/propulsion configuration. Any change, such as altering the ignition time of the traveling charge, could lead to different results.

VII. COMPARISON WITH OPTIMIZED ALL "BOOSTER" CASES

Based upon the results of the Ignition Time Study and Burn Rate Study it appears that for a configuration of 34 g of "booster" and 8 g of traveling charge that the optimum velocity is approximately 2020 m/s if maximum gun pressure is restricted to the maximum pressure due to the "booster". For 34 grams of "booster" in the test fixture being utilized this corresponds to a

pressure of 349 MPa. The obvious question is: "What performance could be expected if the gun system was optimized for a conventional propellant configuration with the maximum pressure restricted to 350 MPa?" To answer this question optimization studies were performed utilizing the XKTC computer code. The results are summarized below.

TABLE 5. Results of Optimized Conventional Firings

OPTIMIZATION
Maximum Pressure < 350 MPa

Propellant	Weight	Velocity
Non-deterred Ball	50 g	1780 m/s
Seven Perforations	60 g	1900 m/s
20% Traveling Charge	42 g	2020 m/s

As can be seen from the above the traveling charge configuration performs better, in terms of increased velocity, than an optimized conventional propellant charge by approximately 120 m/s. This corresponds to a 6% velocity increase.

VIII. CONCLUSIONS AND FUTURE WORK

The conclusions of this initial modeling effort in support of a U.S. Army undertaking to demonstrate the viability of the traveling charge effect can be summarized as follows:

The XNOVAKTC computer code is applicable to small caliber gun firings. This includes conventional and traveling charge configurations. Predictions in regards to breech pressure, velocity, and timing are excellent. However, downbore pressure results show larger than expected deviations.

The following conclusions are based upon a specific gun/propulsion system and may not be the same for different systems.

The ignition time study indicates that the greatest improvement in the traveling charge effect will occur if the ignition of the traveling charge is delayed past the time of maximum pressure due to the "booster" charge.

The ignition time study indicates that the traveling charge effect may be insensitive to the burning behavior, in terms of the burning rate law utilized, of the traveling charge as long as the total burning time for the traveling charge is within a given range.

The burning rate study indicates that relatively large changes in burn rate (+/-30%) do not appreciably change muzzle velocity but can lead to large changes in maximum pressures.

Burn out of the traveling charge results in a large drop in base pressure. See Figure 16.

Areas in which further computations are felt to be needed include:

Investigation into the source of the discrepancy between downbore pressures predicted by XNOVAKTC and those observed in actual gun firings.

Generalization of the effects of traveling charge ignition time and burning behavior on ballistic performance based upon various gun/propulsion systems.

Investigation of the effect the burnout location of the traveling charge has on base pressure and subsequent ballistic performance.

Investigation of the effect of different ratios of "booster" charge to traveling charge on ballistic performance.

Investigation of the effect of using the kinetic options in XKTC to model the traveling charge propellant. The kinetic options allow for a delayed chemical reaction of the traveling charge propellant.

Investigation of the origin of the resistance profile used in modeling the experimental firings. This investigation will be performed in an experimental program.

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APPENDIX A

Tables A-1 and A-2 give the maximum pressures, at the indicated gages, and muzzle velocities for the two different burn rate laws used in the ignition time study.

TABLE A-1. Ignition Time Study - Constant Burn Rate

Ignition Time(ms)	G1 MPa	G2 MPa	G3 MPa	G5 MPa	G7 MPa	Velocity m/s
0	N/A	N/A	N/A	N/A	N/A	N/A
.475	497	494	469	81	30	1998
.95	436	426	365	67	28	1926
1.15	373	364	399	55	28	1895
1.35	349	346	288	52	22	1946
1.55	349	346	288	49	22	1980
1.75	349	346	288	124	21	2017
*	496	492	394	71	33	1897

Note: Results for an ignition delay of 0 ms was not obtained due to difficulties with XKTC

* 42 g All "Booster" Case

TABLE A-2. Ignition Time Study - Pressure Dependent Burn Rate

Ignition Time(ms)	G1 MPa	G2 MPa	G3 MPa	G5 MPa	G7 MPa	Velocity m/s
0	498	498	427	78	29	2011
.475	530	541	457	76	28	2035
.95	573	546	570	84	31	1989
1.15	535	437	626	73	38	1903
1.35	349	346	288	50	20	1917
1.55	349	346	288	47	21	1979
1.75	349	346	288	86	20	2018
*	496	492	394	71	33	1897

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